UNAM 5th Workshop on High p-T Physics at LHC 2010 SMF

Underlying Event Studies at ATLAS and CDF

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On behalf of the ATLAS and CDF Collaborations

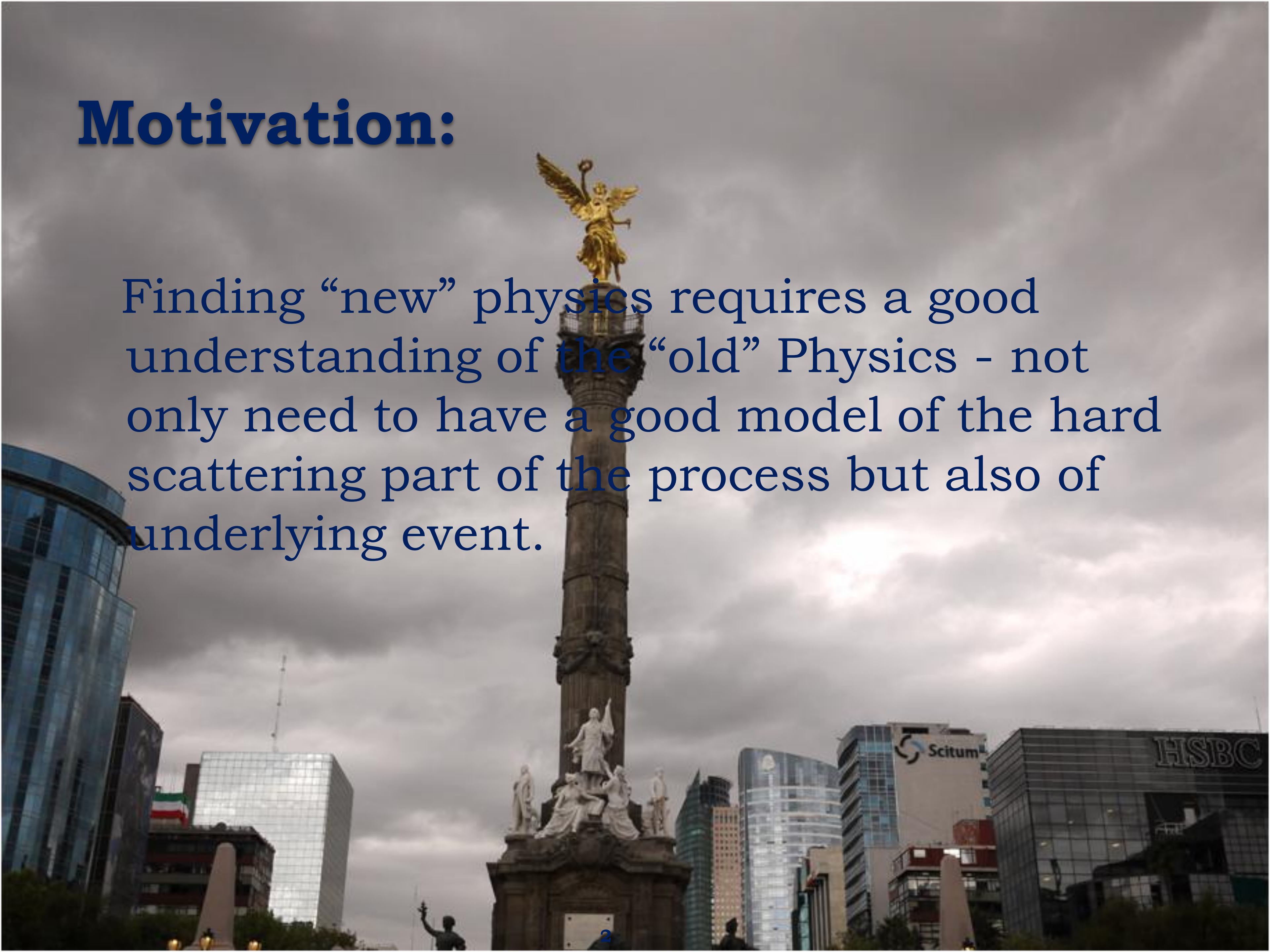
ATLAS

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

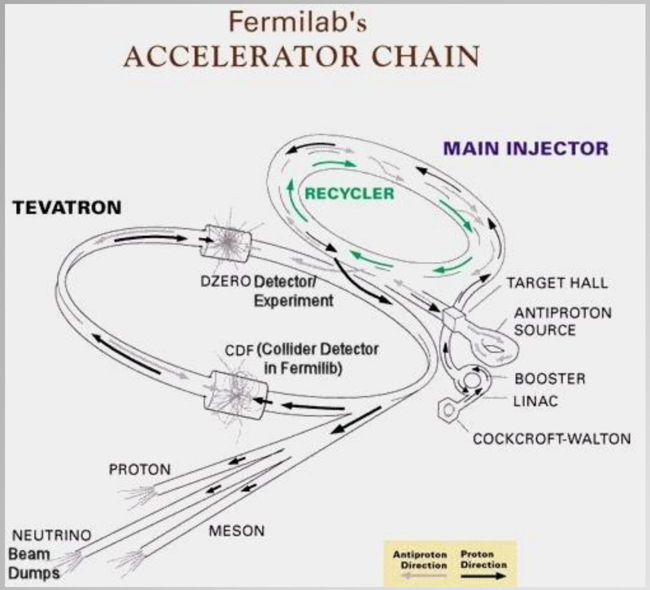
CDF II

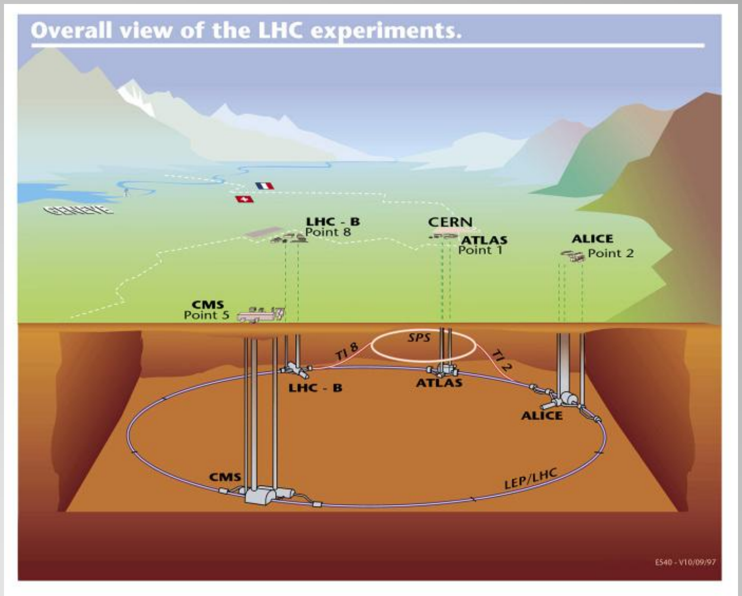
Motivation:

Finding “new” physics requires a good understanding of the “old” Physics - not only need to have a good model of the hard scattering part of the process but also of underlying event.



Tevatron to LHC





Not only: 4x longer tunnel, 2x larger magnetic field and 3.5x more CM energy, 10x more instantaneous luminosity

… but also: pp collisions from ppbar, larger QCD cross section

Tevatron to LHC

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Outline

- Underlying Event: what, why, how.

- Results, corrected back to particle level.
  CDF: *Phys. Rev. D 82, 034001 (2010).*
  ATLAS: *ATLAS-CONF-2010-081.*

- Conclusions and outlook.

So what is this "Underlying Event"?

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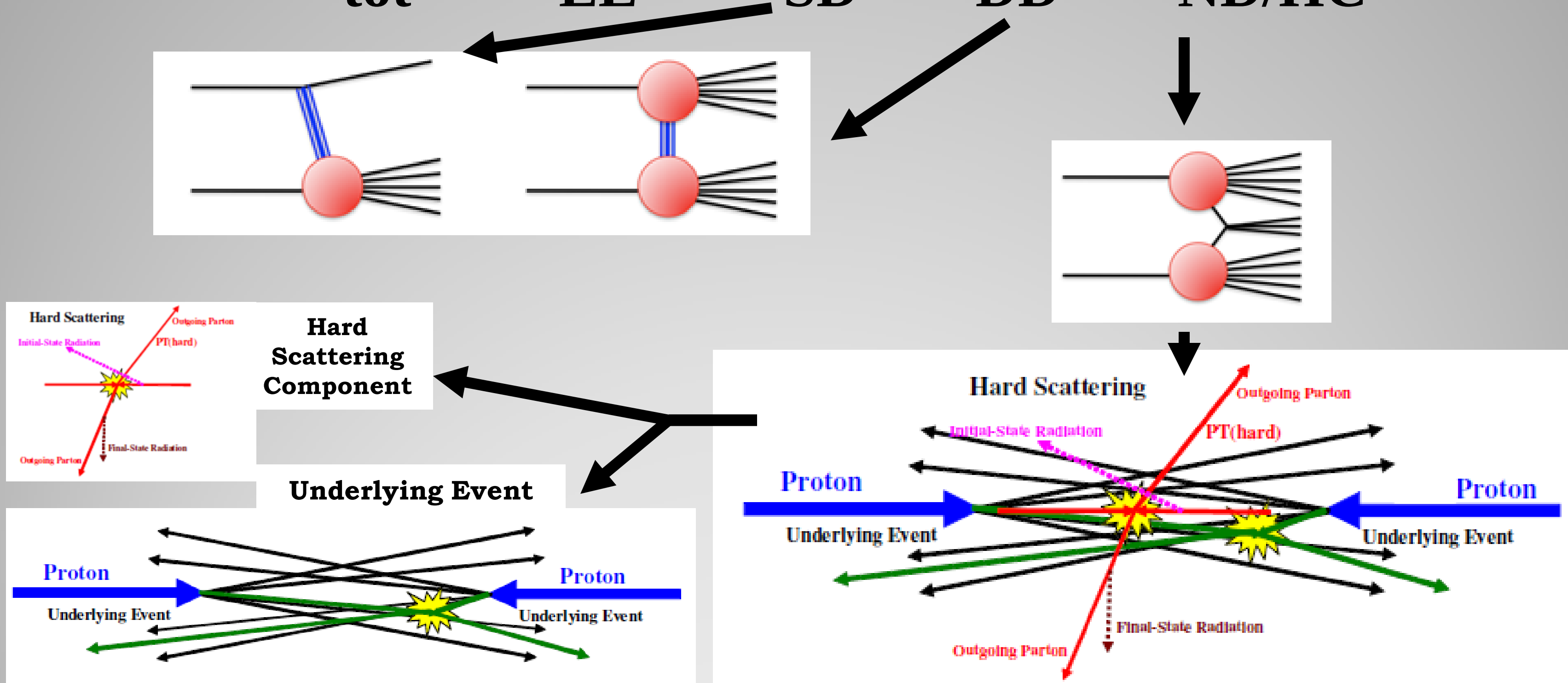
Thanks to Stan Lai for this!

“Soft” QCD

$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND/HC}$$



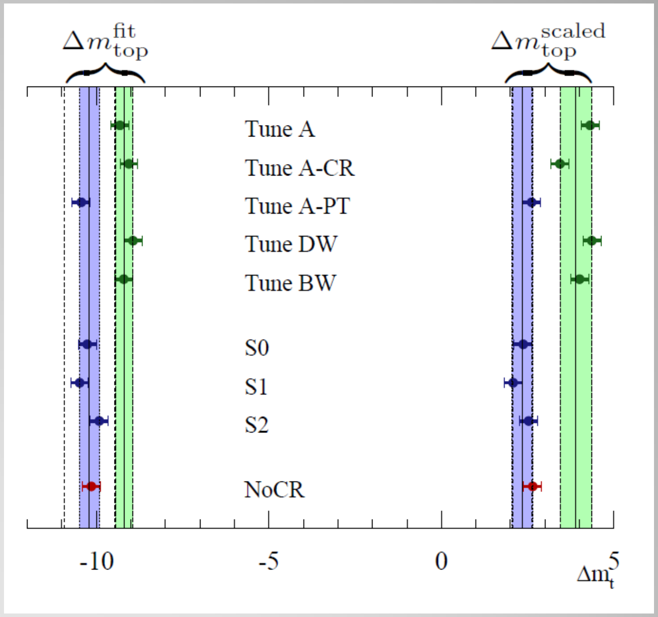
Minimum-bias: events collected with (ideally) totally inclusive trigger, in principle contains all types of interactions proportionally to their natural production rate.
Underlying event: “connected” with the hard scattering.

What is the problem with the Underlying Event?

- The process of interest at hadron colliders are mostly the hard scattering events.
- These hard scattering events are contaminated by the underlying event.
- The underlying event is an **unavoidable background** to most collider observables.
- Increasing luminosity implies more hadronic collisions – which also complicates things. ***(pile-up)***
- The underlying event is not well understood since **non-perturbative physics** is involved. And from an experimental point of view, on an event by event basis, it is impossible to separate the UE component.

Measuring it is important in …

- Precision measurements of hard interactions where soft effects need to be subtracted.
- Jet cross-section, missing energy, isolation cuts, top mass …
- QCD Monte-Carlo tuning. Parameters in MC models that are constrained by soft QCD measurements have implications for predictions of high energy processes.



Eur.Phys.J.C52:133-140,2007

Higher the precision, higher the accuracy of physics measurements.

- So we have to use the underlying event distributions to test the phenomenological models and "tune" the Monte-Carlo event generators to give the best description of the data.

- We gain deeper insight if data does not match up with Monte-Carlo predictions, which reflect our current understanding of these processes.

PYTHIA

For underlying event studies, the only tool we have is to compare the data and the **predictions** from various Monte Carlo event generators, i.e. PYTHIA.

Apollo's priestess, Pythia, performing the duty of the oracle

PYTHIA has "knobs" which can be *tuned* to obtain an optimal description of the data.

PYTHIA Parameters

PYTHIA UE Parameter	**Definition**
MSTP(81)	MPI on/off
MSTP(82)	3 / 4: resp. single or double gaussian hadronic matter distribution in the p / pbar
PARP(67)	ISR Max Scale Factor
PARP(82)	MPI pT cut-off
PARP(83)	Warm-Core: parp(83)% of matter in radius parp(84)
PARP(84)	Warm-Core: ”
PARP(85)	prob. that an additional interaction in the MPI formalism gives two gluons, with colour connections to NN in momentum space
PARP(86)	prob. that an additional interaction in the MPI formalism gives two gluons, either as described in PARP(85) or as a closed gluon loop. Remaining fraction is supposed to consist of qqbar pairs.
PARP(89)	ref. energy scale
PARP(90)	energy rescaling term for PARP(81-82)~E_{CM}^PARP(90)

PYTHIA Parameters

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PARP(82)	MPI pT cut-off

- PYTHIA uses MPI to enhance the UE.
- Multiple parton interaction more likely in a hard (central) collision.
- ISR Max Scale Factor affects the amount of initial-state radiation.
- Increasing the cut-off decreases the multiple parton interaction.

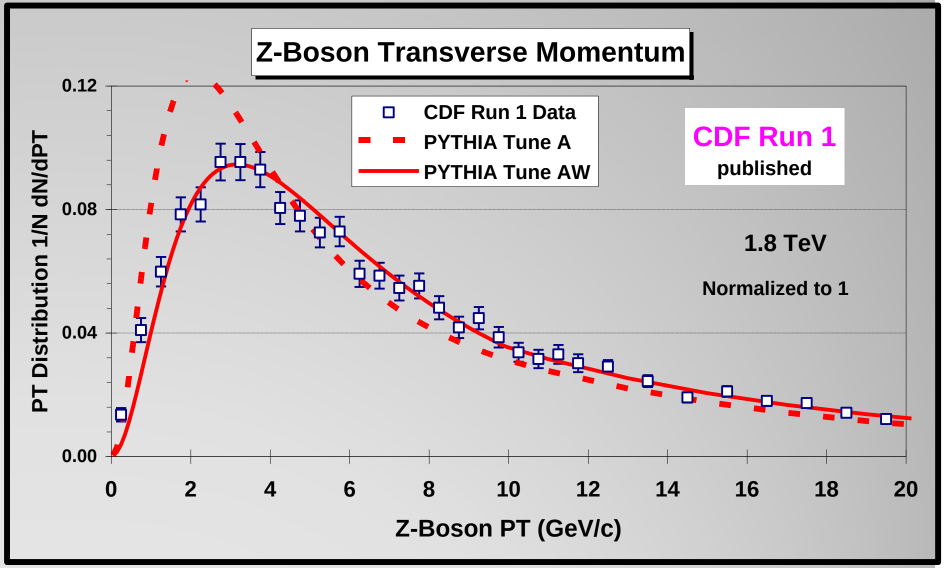
CDF Run 1 Tune (PYTHIA 6.2 CTEQ5L)

UE Parameters

ISR Parameters

Intrinsic KT

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0



Both tunes reveal a remarkably good agreement of the data and PYTHIA.

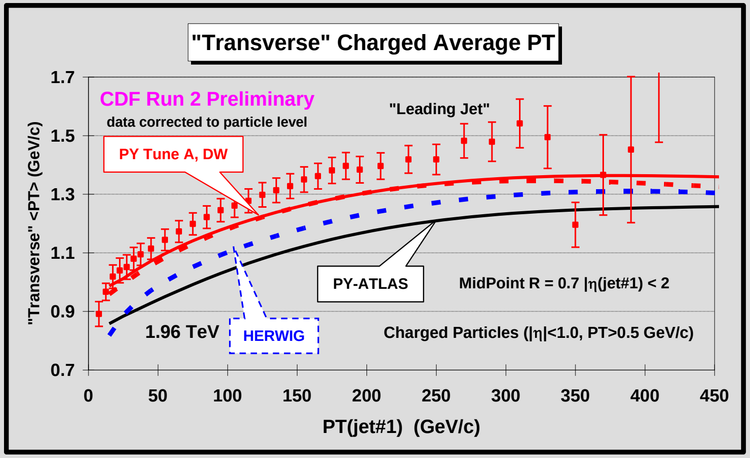
CDF Run 2 Tune (PYTHIA 6.206 CTEQ5L)

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune A	Tune DW	Tune DWT
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV
PARP(90)	0.25	0.25	0.16
PARP(62)	1.0	1.25	1.25
PARP(64)	1.0	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	1.0	2.1	2.1
PARP(93)	5.0	15.0	15.0



PYTHIA Tune DW is very similar to Tune A except that it fits the CDF $P_T(Z)$ distribution and it uses the DØ prefered value of PARP(67) = 2.5.

LHC Era Tunes

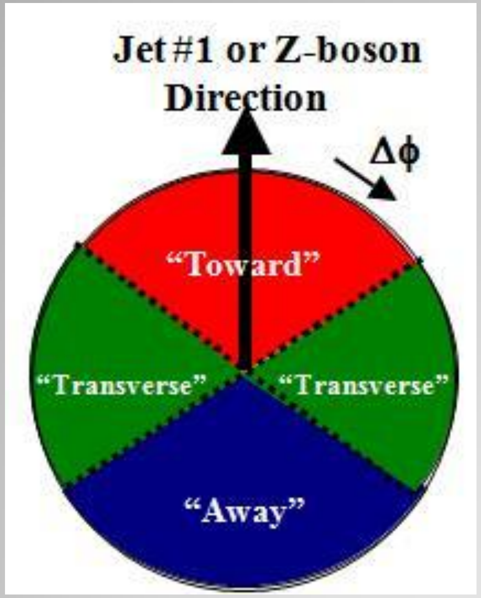
- Moved from old Q^2-ordered parton Showers to p_T-ordered parton showers and new MPI models in PYTHIA.
- New **A**TLAS **M**inimum **B**ias **T**une (**1**) using diffraction suppressed Min-Bias data and plateau of UE data and LO* pdf. (ATLAS-CONF-2010-031)
- Rick Field's tune Z1 varying PARP(82) and PARP(90) and using CTEQ5L pdf from AMBT1.

AMBT1 and Z1

Table from R. Field

Parameter	Tune Z1 (R. Field CMS)	Tune AMBT1 (ATLAS)
Parton Distribution Function	CTEQ5L	LO*
PARP(82) – MPI Cut-off	1.932	2.292
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.25
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

Dividing up the Central Region

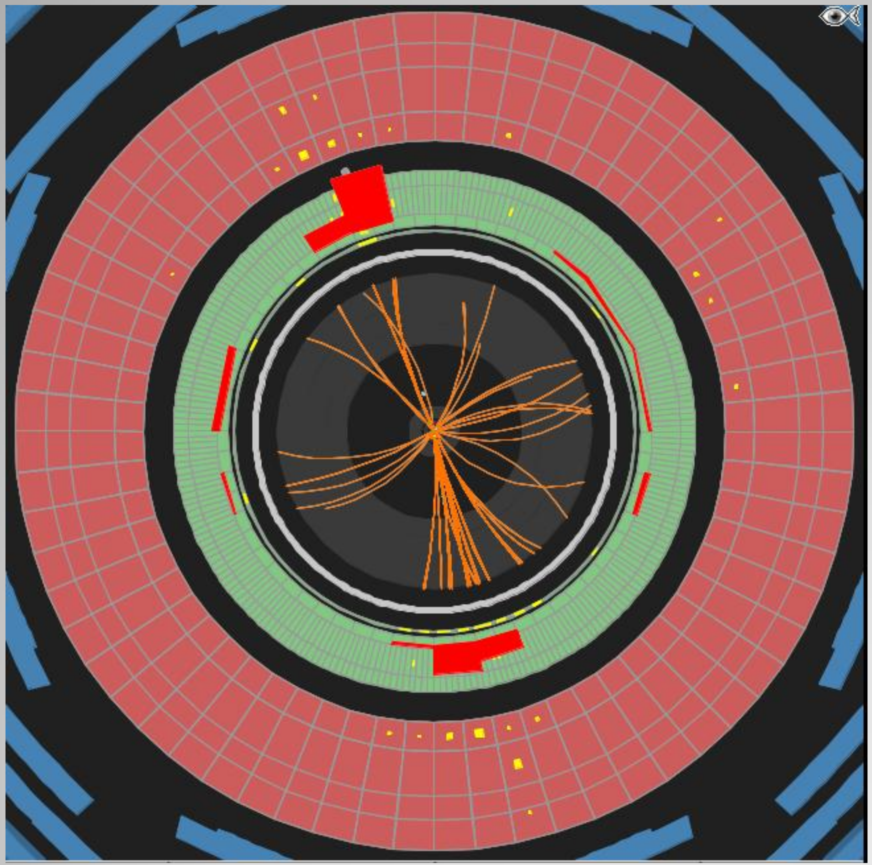


We define –

- $|\Delta\phi| < 60^o$ as **Toward**
- $60^o < |\Delta\phi| < 120^o$ as **Transverse**
- $|\Delta\phi| > 120^o$ as **Away**

Azimuthal angle Δϕ relative to the leading hard scattered object.

A nice dijet even seen in ATLAS detector:



Run: 153565, Event:24177058

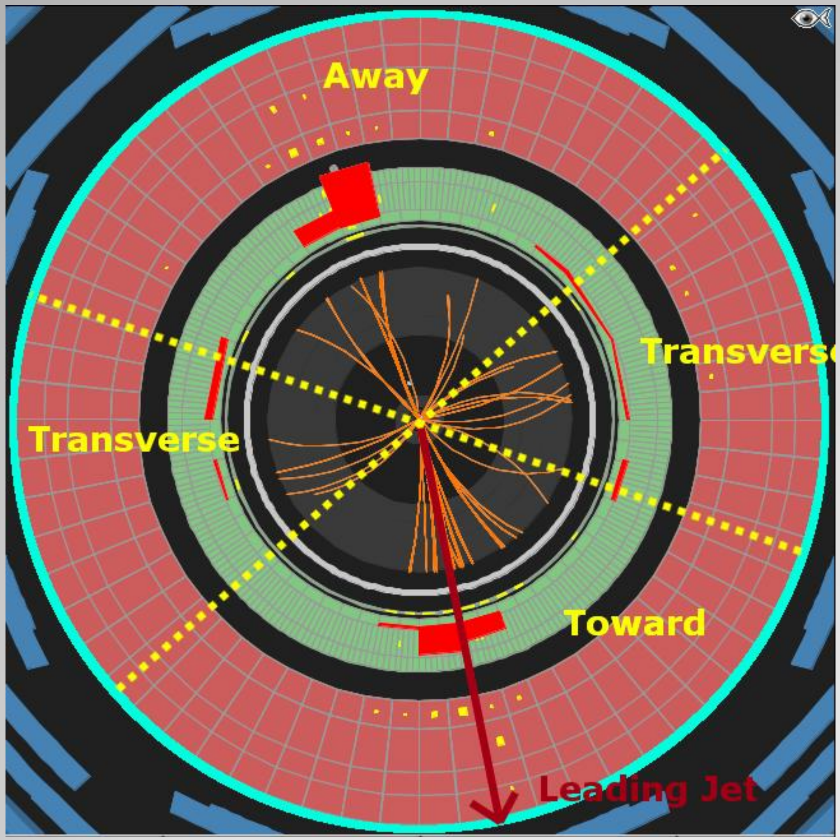
Leading Jet:

$p_T = 69.7$ GeV

$\eta = 1.3$ iRad

$\phi = -1.4$ rad

A nice dijet even seen in ATLAS detector:



Leading Jet:

$p_T = 69.7$ GeV

$\eta = 1.3$ iRad

$\phi = -1.4$ rad

Transverse:

$N_{chg} = 9$

$\sum p_T^{chg} \cong 10$ GeV

$\bar{p_T} \cong 1.1$ GeV

Run: 153565, Event:24177058

Underlying Event Studies

CDF	ATLAS
Leading calorimeter jet (MidPoint R = 0.7) in the region $\|\eta\| < 2$. Z undergoing Drell-Yan decay (Using events with the lepton pair invariant mass in the Z region: 70 < M(ll) < 110 GeV).	Leading track with $p_T > 1$ GeV. (At low energies and with limited statistics, sufficient to use the leading track)
Charged particles with: $p_T > 0.5$ GeV and $\|\eta\| < 1$	Charged particles with: $p_T > 0.5$ GeV and $\|\eta\| < 2.5$
Data corrected back to particle level so that it can be used to tune the QCD Monte-Carlo models without requiring detector simulations.	

Observables sensitive to UE

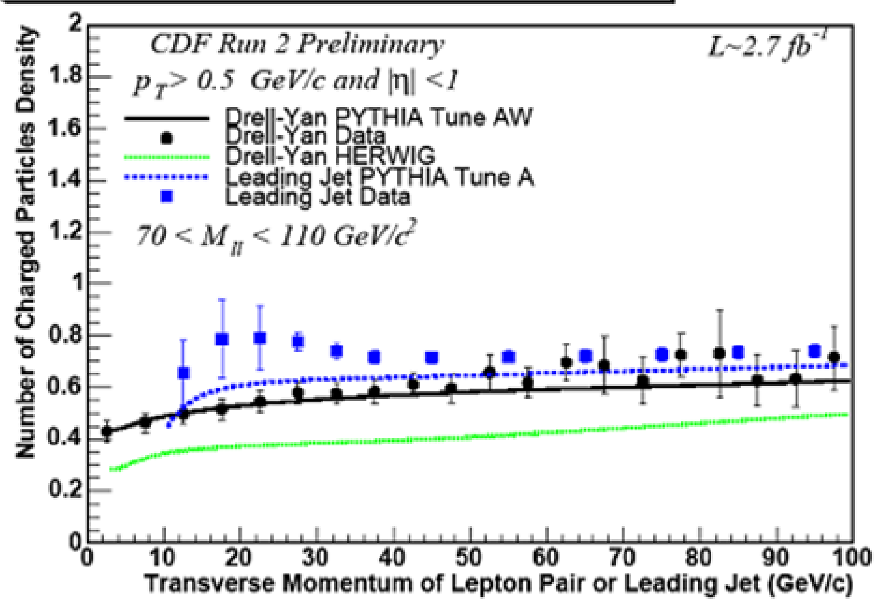
As a function of Leading jet (LJ) or leading track (LT) or lepton pair p_T (DY):	
Number density	Number of charged particles per unit eta-phi
p_T density	Scalar p_T sum of charged particles per unit eta-phi
$< p_T >$	Average p_T of charged particles Require at least 1 charged particle
As a function of number of charged particles:	
$< p_T >$	Average p_T of charged particles Require. at least 1 charged particle

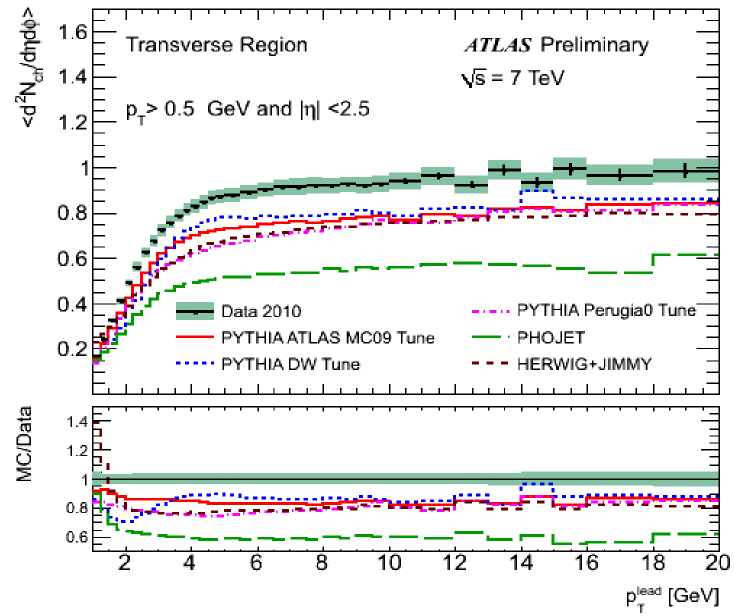
$<p_T>$ is constructed on an event-by-event basis and then averaged over the events.

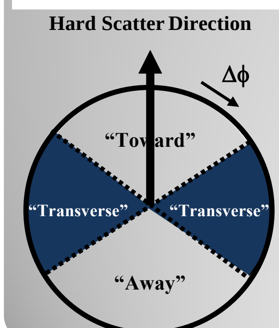
Results(I):
The underlying event observables as a function of the leading p_T

Charged Particle Multiplicity

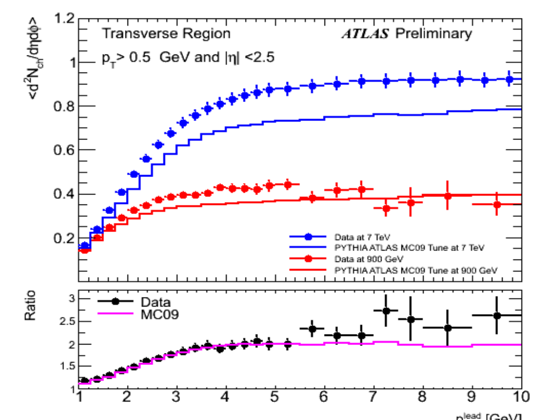
Transverse Region Charged Particle Density: dN/dηdφ



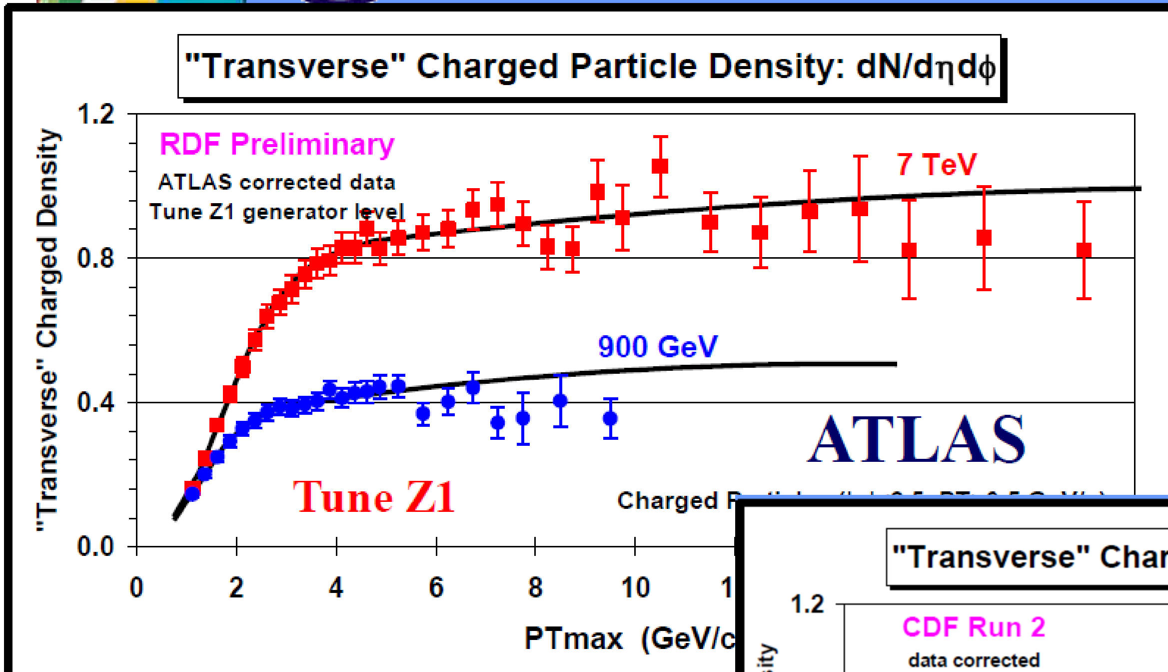




- CDF LJ: PYTHIA tune A does not have quite enough activity
- CDF DY: Better agreement with tune AW
- ATLAS LT: UE more active than predicted by all pre-LHC tunes
- ATLAS LT: Energy extrapolation modeled well

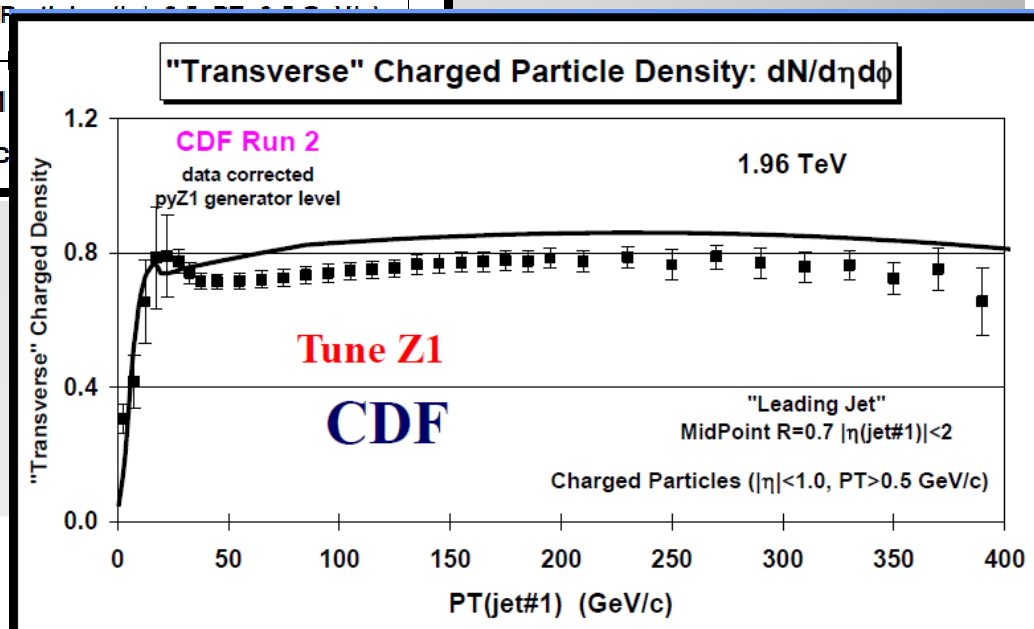


Charged Particle Multiplicity



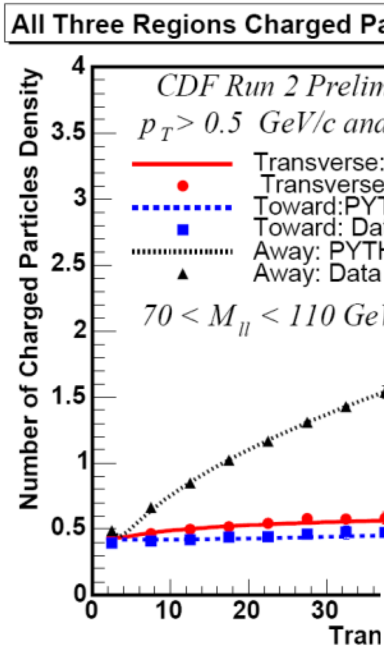
RDF tune Z1 predicts ATLAS UE activity better

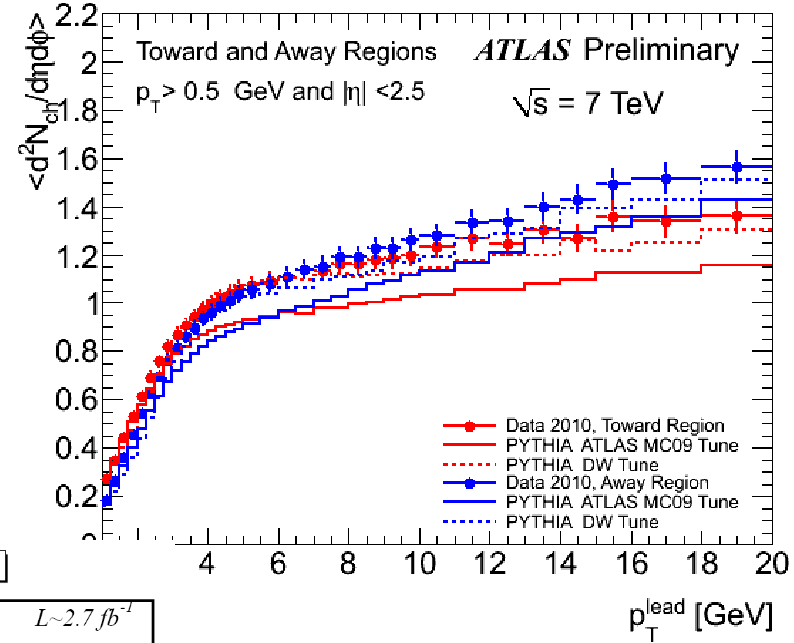
However tune Z1 is overestimates for CDF UE activity

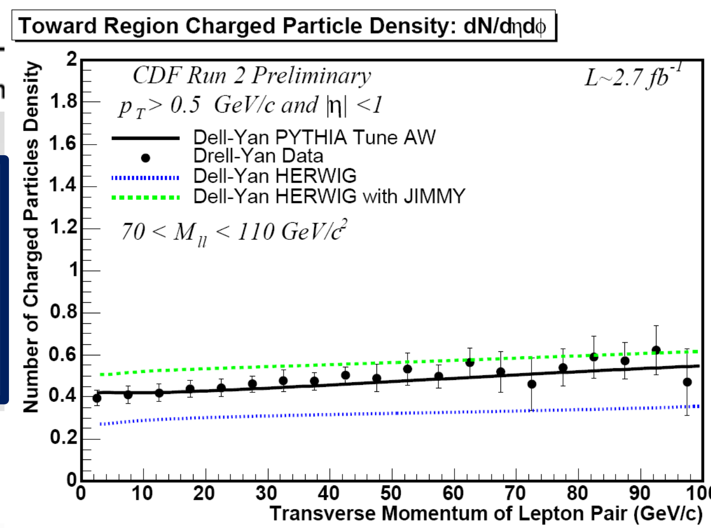


From Rick Field's LPCC joint UE&MB WG meeting talk on 9/7.

Charged Particle Multiplicity







CDF DY:

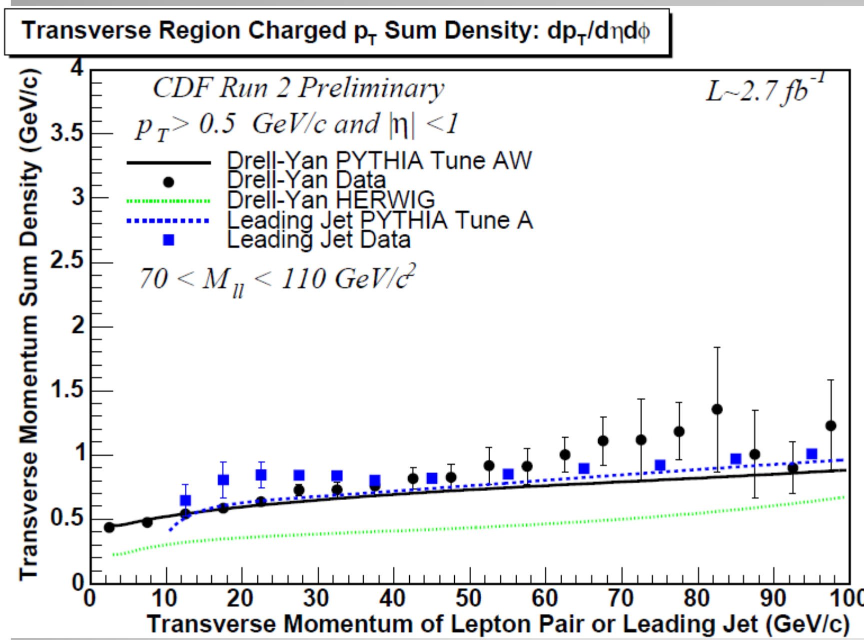
Herwig too less, Herwig+Jimmy too much!

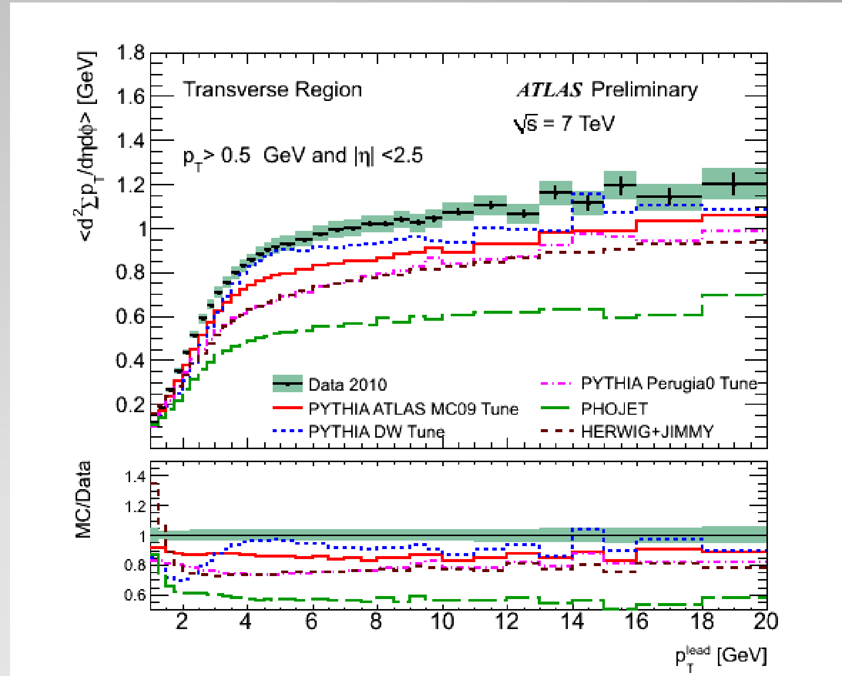
ATLAS LT:

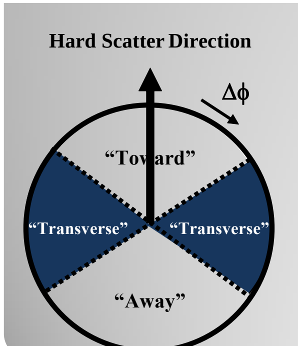
DW is the best!

Notice the “crossover”!

Charged Transverse Momentum Sum

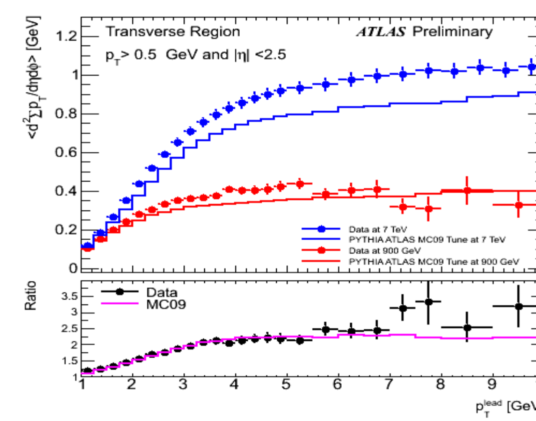




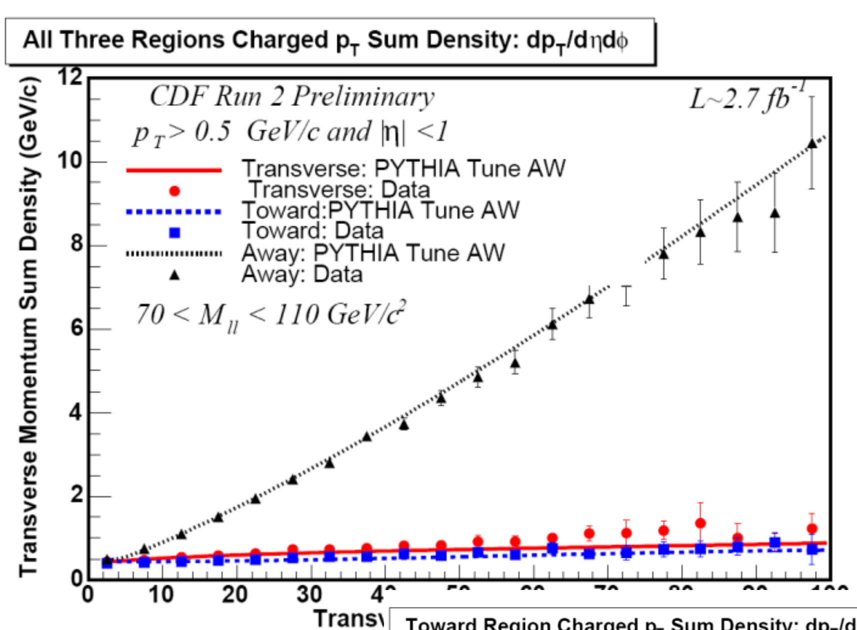


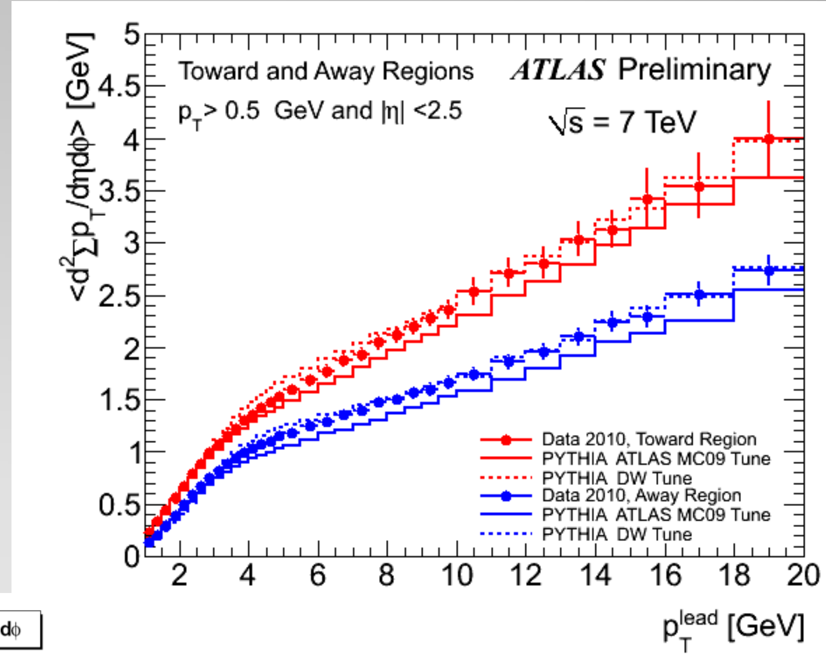
Pre-LHC tunes model CDF data better than ATLAS data.

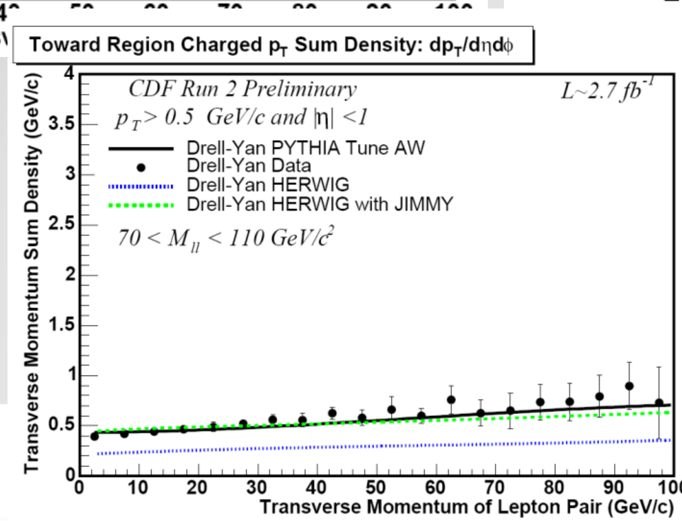
The higher number density implies a higher p_T density as well for ATLAS LT.



Charged Transverse Momentum Sum







CDF DY:

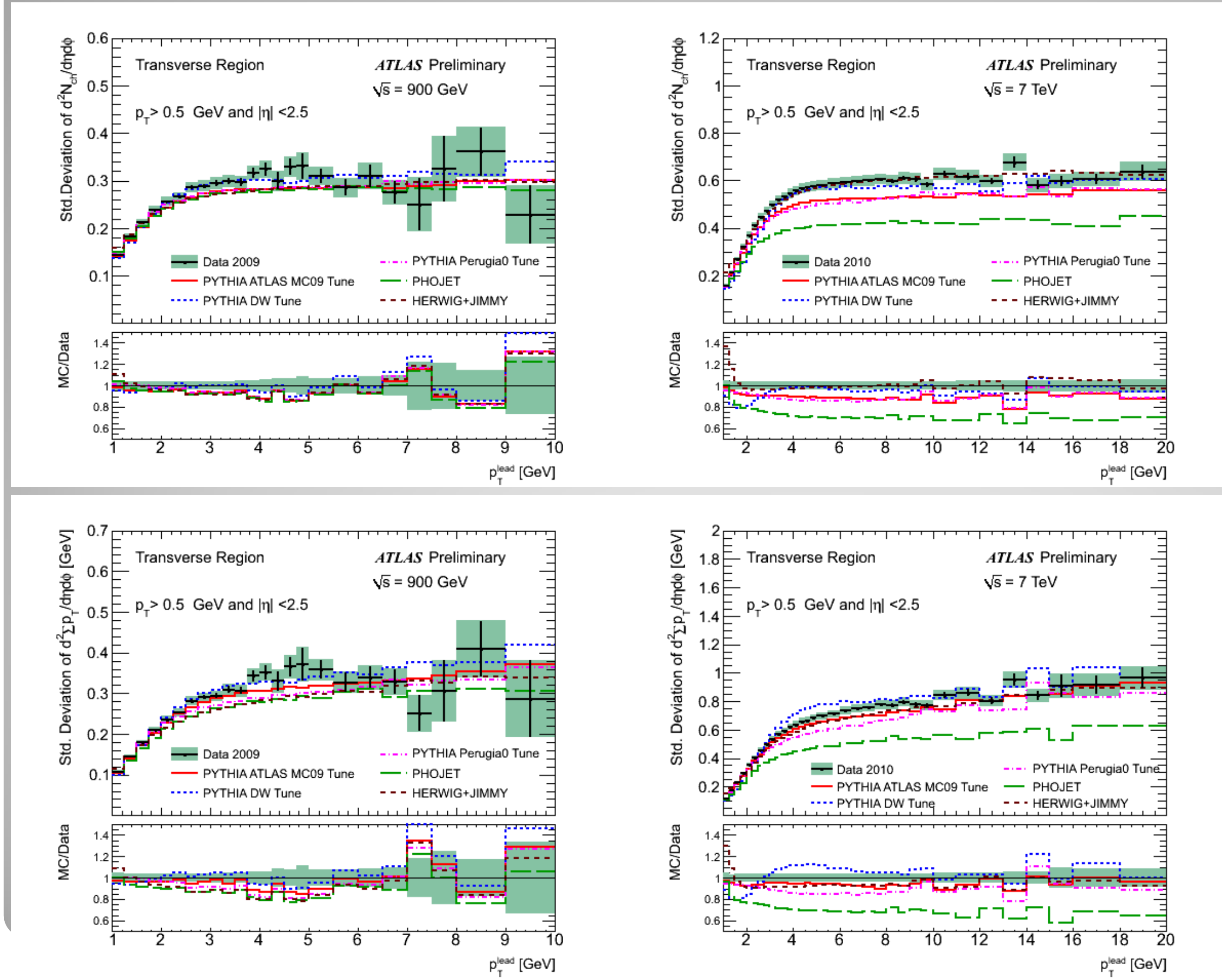
Herwig too soft, so matches well, Herwig+Jimmy too much!

ATLAS LT:

DW is the best!

Larger probability of higher p_T particles produced in association with the leading track.

ATLAS Transverse Region Variances

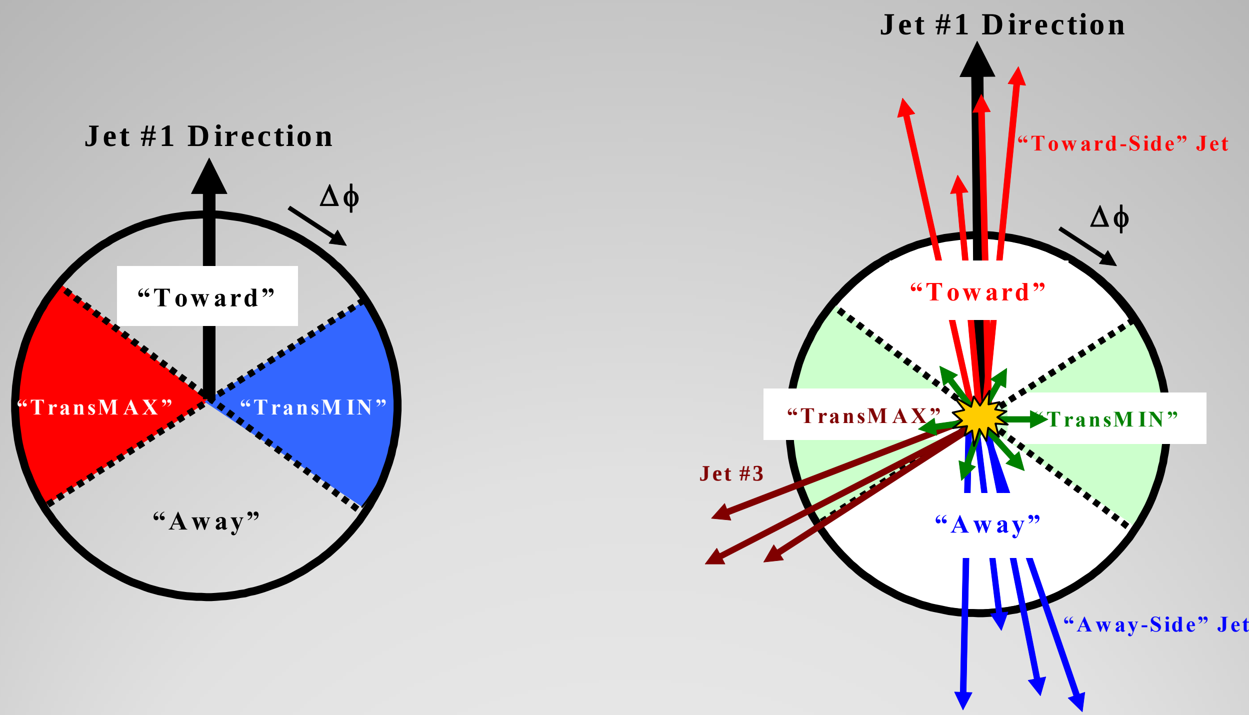


S.D. lower than mean, but more than square root of mean.

Suggests tracks not independently produced (not Poisson distribution).

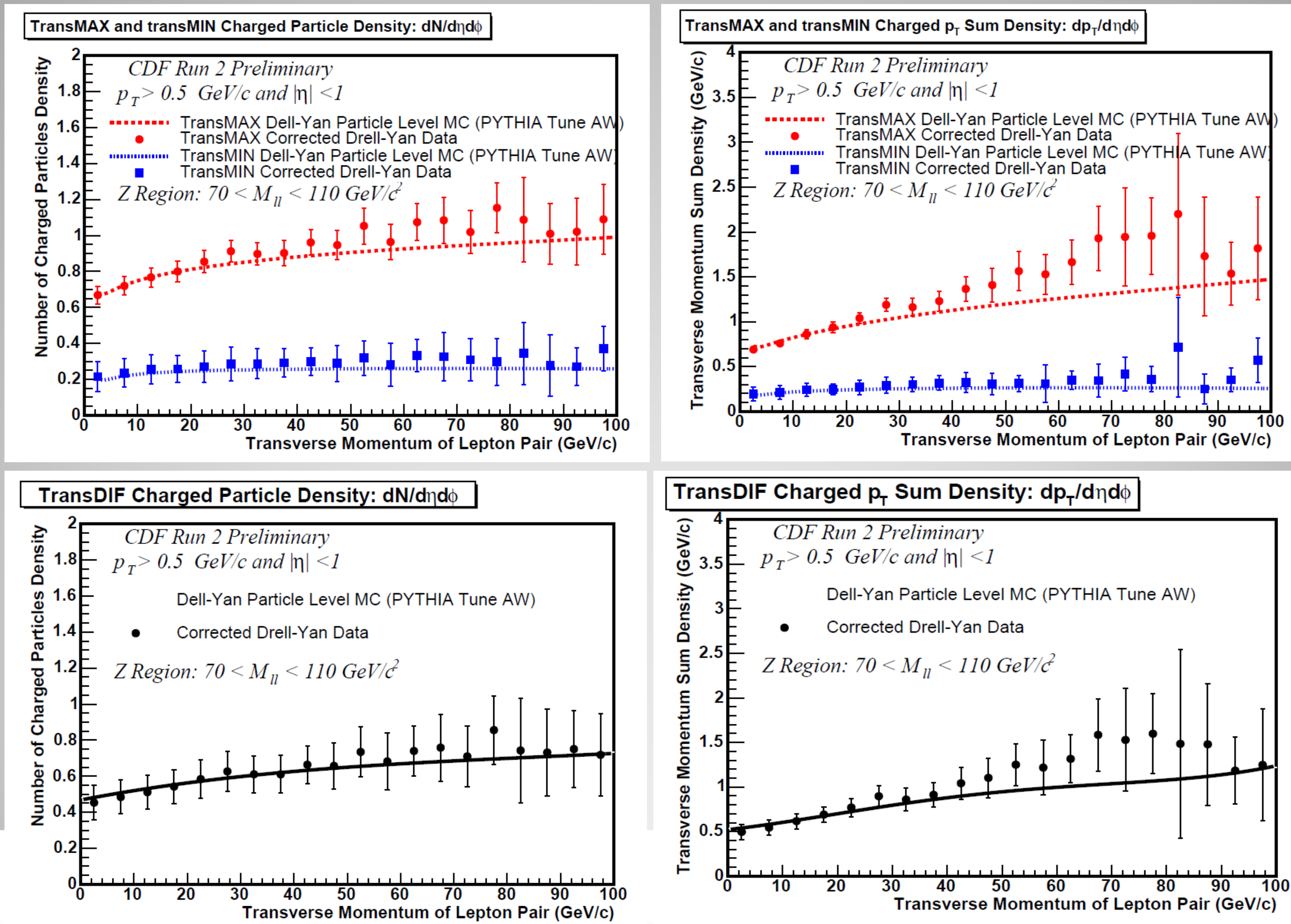
S.D. provides a additional constraint on generator tunes

TransMAX, MIN, DIF Regions

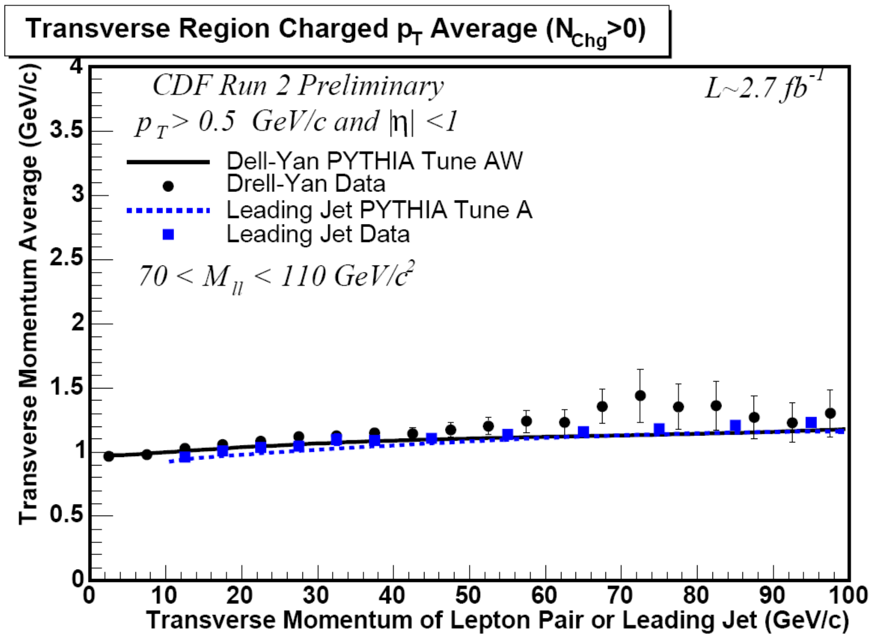


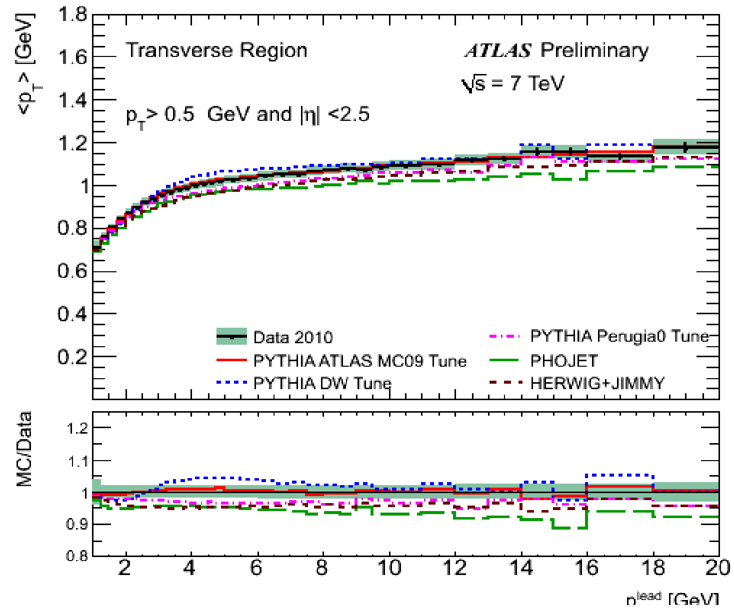
- ➢TransMIN sensitive to the soft BBR component
- ➢TransDIF (TransMAX-TransMIN) sensitive to the hard scattering component (*i.e.* ISR/FSR)

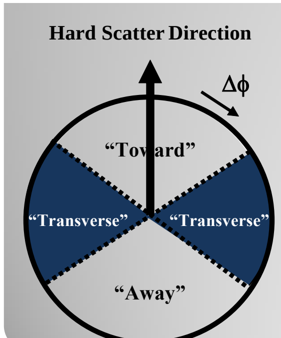
CDF TransMAX, MIN, DIF Results



Charged Transverse Momentum Average

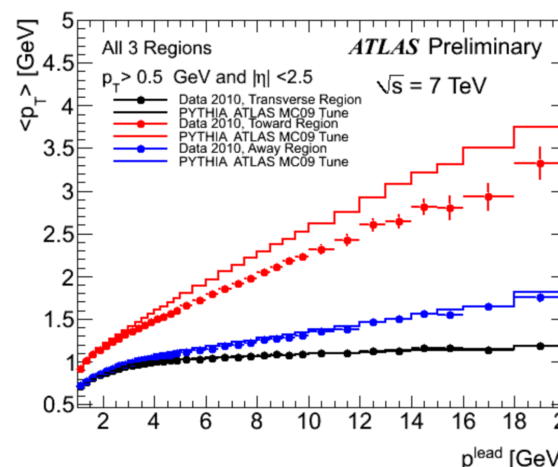




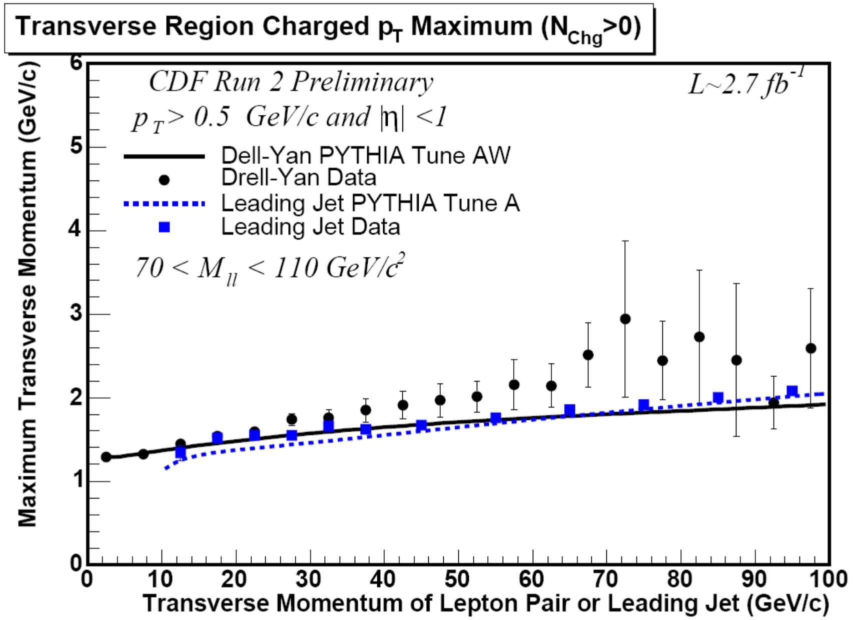


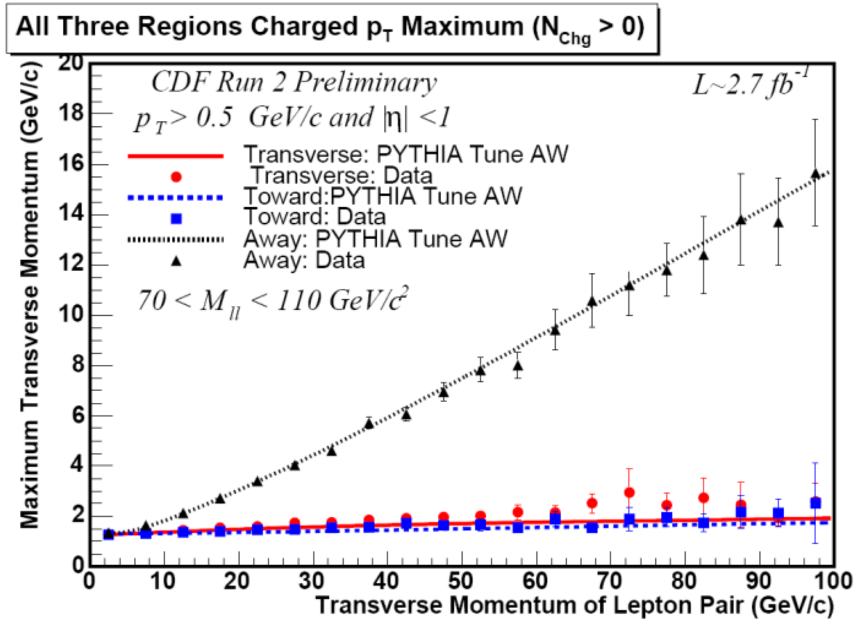
Pre-LHC tunes model CDF data better than ATLAS data, but better agreement than multiplicity and p_T sum. Overestimates in toward and away regions.

CDF LJ and DY very similar.



CDF Charged Transverse Momentum Maximum



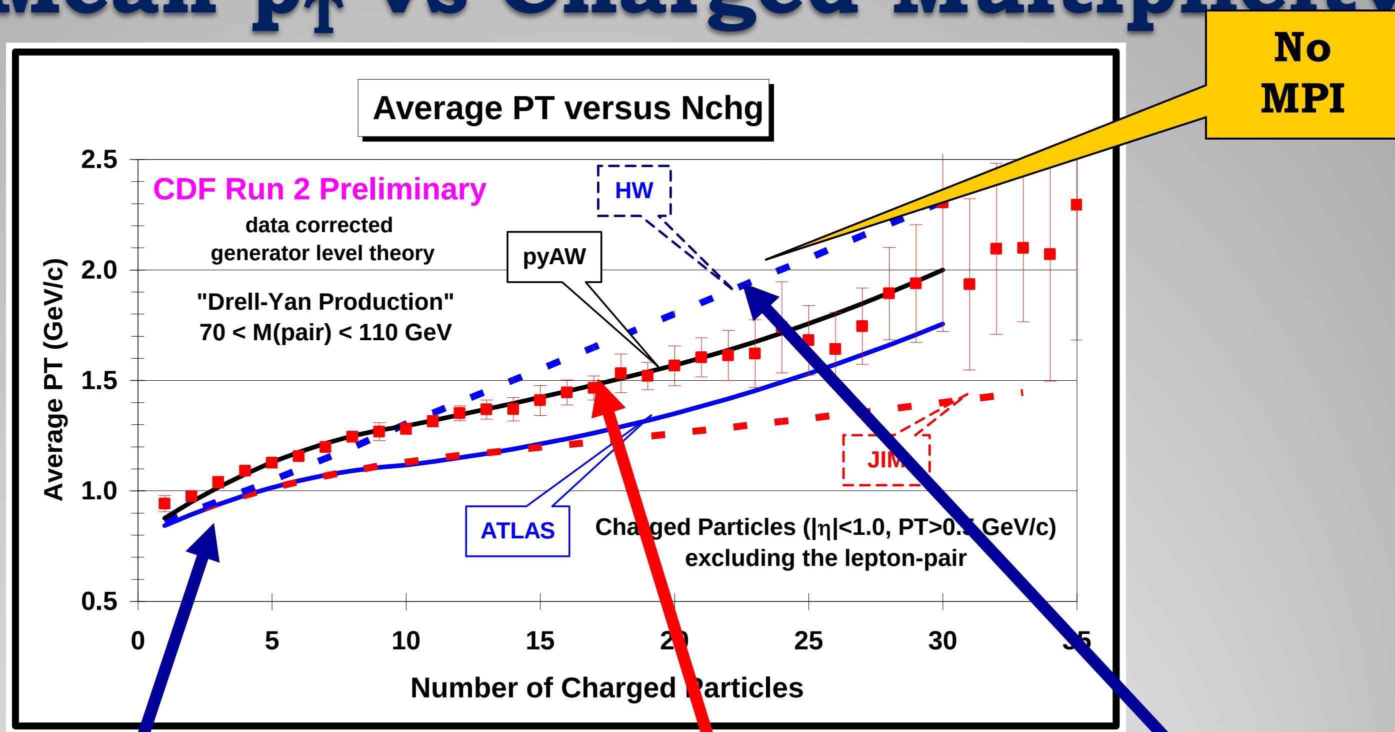


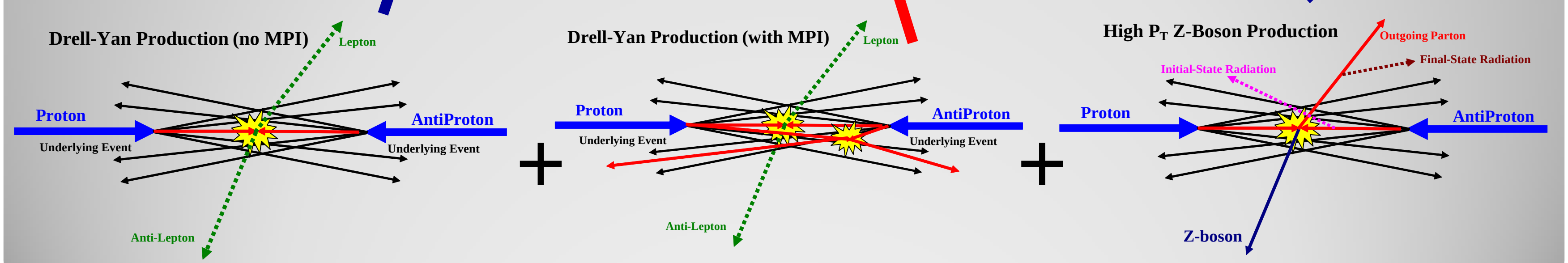
Results (II): Correlation between mean p_T of the charged particles against the charged particle multiplicity

<p_T> versus N_{chg} is a measure of the amount of **hard versus soft** processes contributing and it is **sensitive** to the modeling of the multiple-parton interactions and fragmentation dynamics.

CDF Mean p_T vs Charged Multiplicity

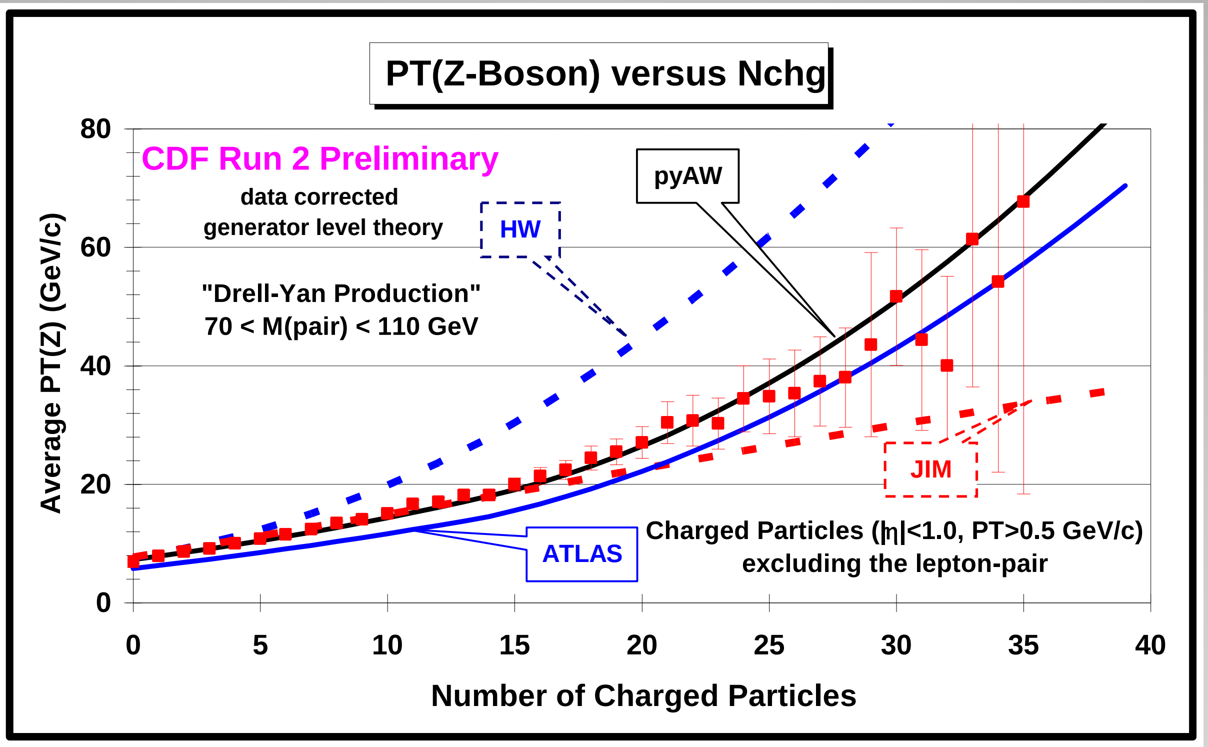
Old ATLAS tune





CDF Mean p_T vs Charged Multiplicity

Old ATLAS tune

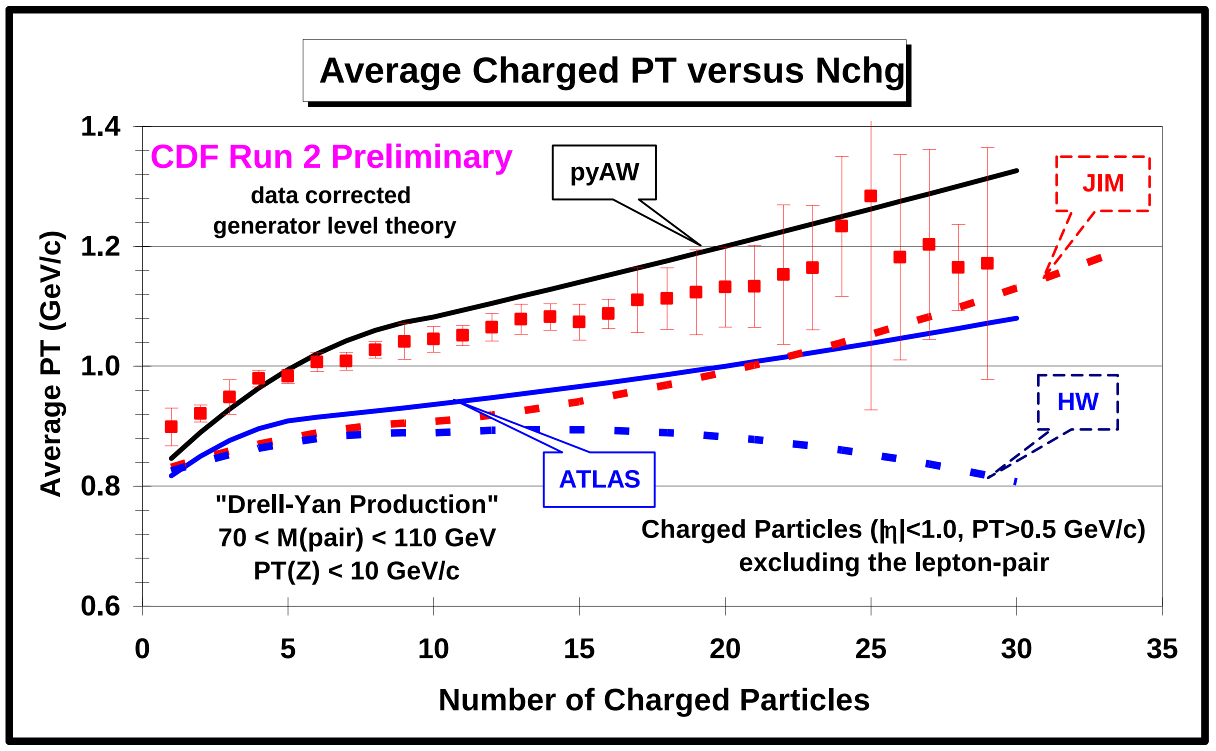


Large N_{chg} implies high p_T jets (i.e. hard 2→2 scattering). Without MPI the only way to get large N_{chg} is to have a very hard 2→2 scattering.

CDF Mean p_T vs Charged Multiplicity

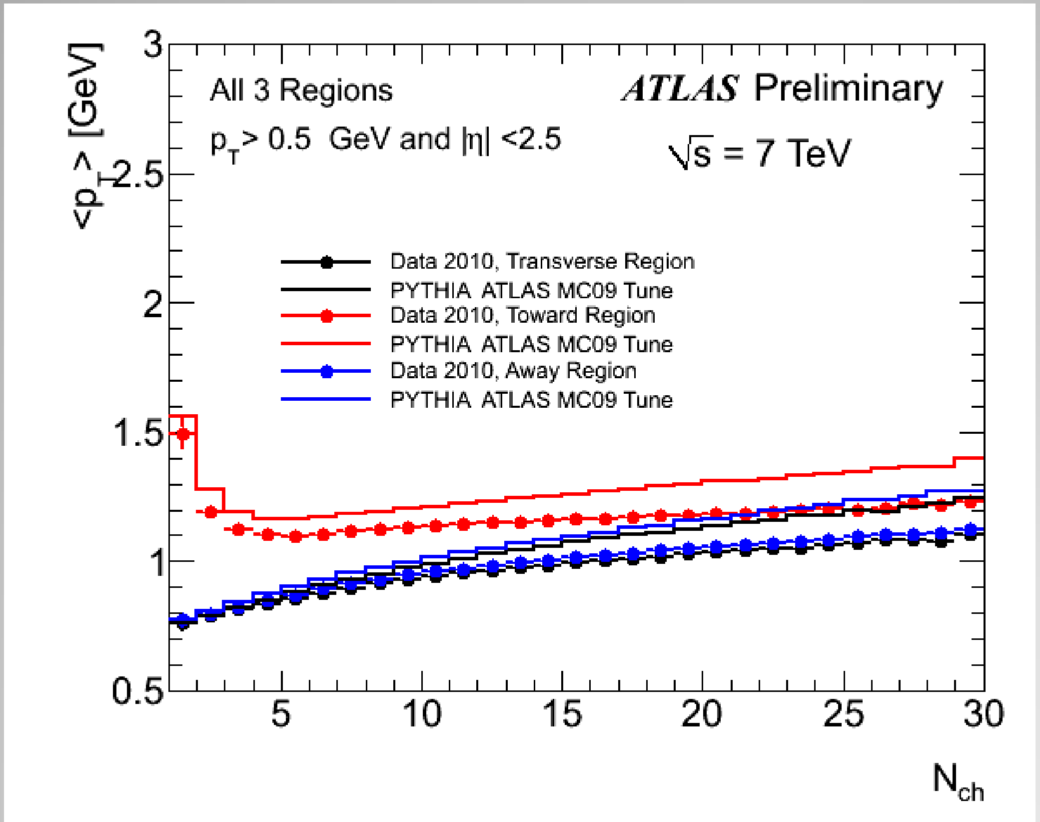
$P_T(Z)$ < 10 GeV

Old ATLAS tune

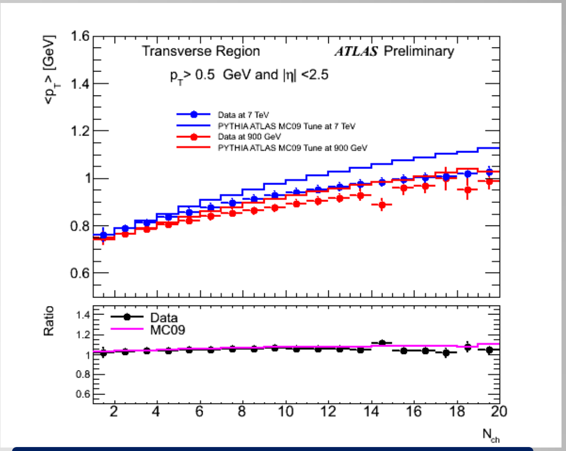


Multiple-parton interactions provides another mechanism for producing large multiplicities that are harder than the beam-beam remnants, but not as hard as the primary Z +jet hard scattering.

ATLAS Mean p_T vs Charged Multiplicity



Observables Calculated only in the relevant regions.



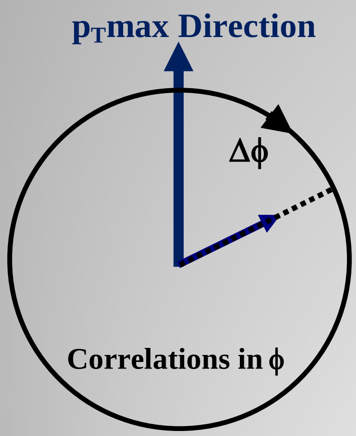
Essentially Independent of collision energy

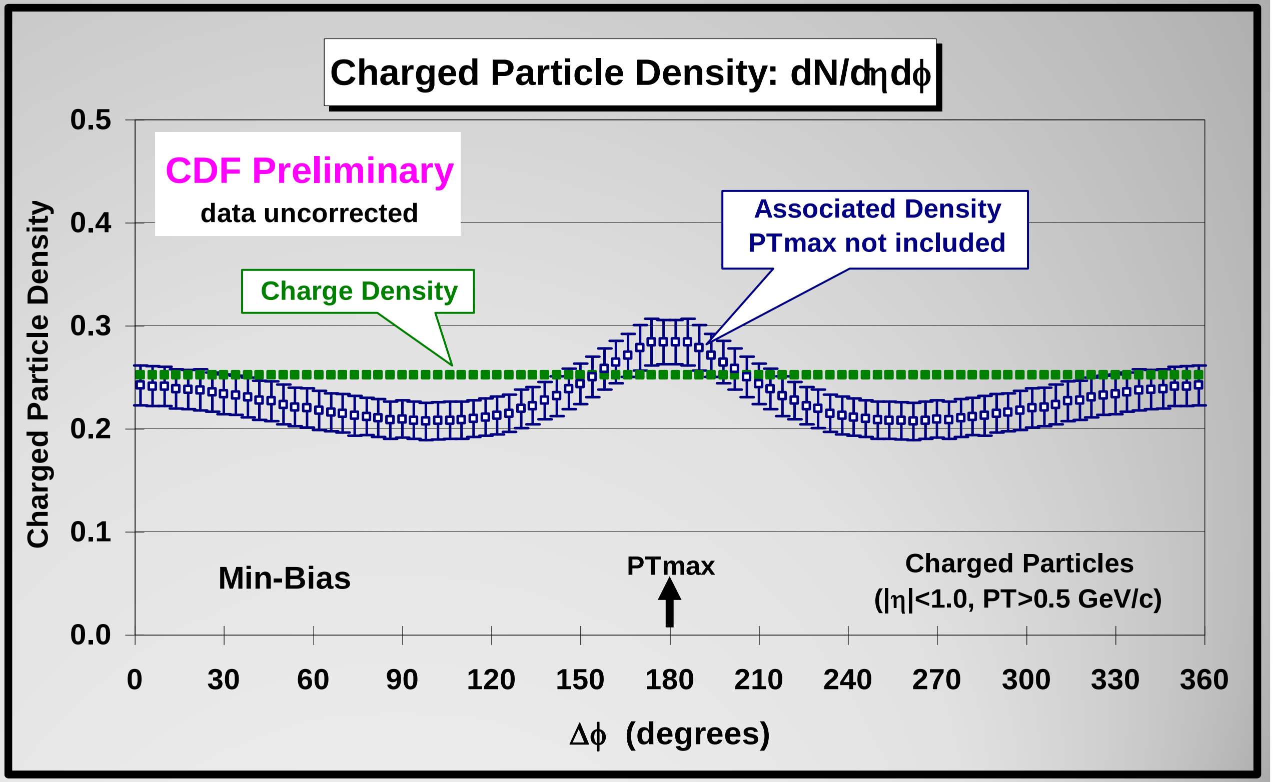
MC predicts harder spectra at high multiplicity part, but all regions very similar. Spike in toward as leading track is included.

Results(III): Angular Distributions

TECHNISCHE UNIVERSITÄT DRESDEN

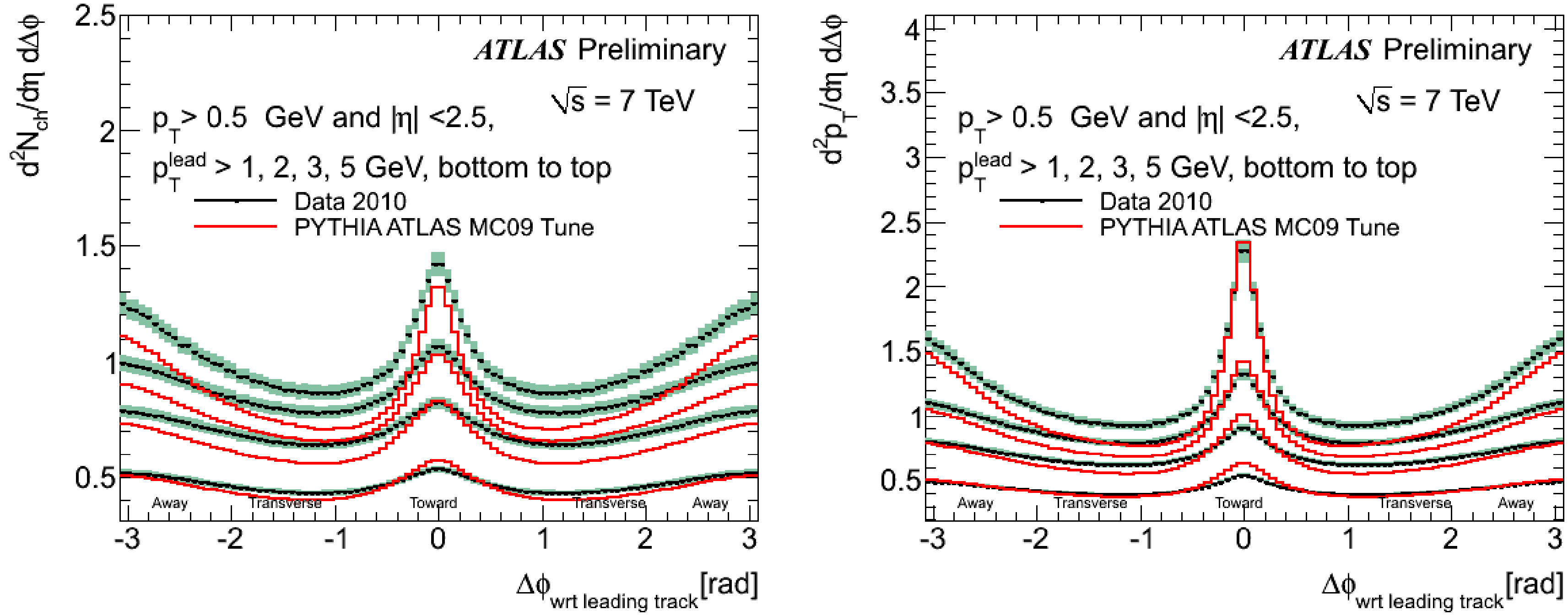
CDF Min-bias Associated Charged Particle Density





Angular Distributions

Lead track not included.
Symmetrized.



With increasing p_T, 'jetlike' structure is observed, significant difference in shape, sharper rise in transverse region compared to MC.

Conclusions

- Observed reasonable agreement with PYTHIA tune A/AW predictions for CDF LJ and DY.
- Similar underlying event results for LJ and DY– underlying event models (BBR part) independent of hard scattering event?
- For both 900 GeV and 7 TeV ATLAS LT, excess of data is seen over MC and shape difference in "deltaphi" plots.
- No current pre-LHC MC tune adequately describes all of the early ATLAS data.

Outlook

- The UE measurement plan at the LHC benefits from the solid experience of the CDF studies.
- CDF underlying event data has been used extensively for Monte-Carlo tuning by ATLAS, CMS and automated tuning tools like PROFESSOR.
- Measurement at two energy points in LHC is crucial to look at the energy extrapolation of the models.
- Early ATLAS data is essential input for tuning.
- Future underlying event measurement plans in ATLAS include (but not limited to) looking at topoclusters, trackjets, calojets, W/Z+jets, using rapidity gaps, jet shapes, Fourier transform techniques.

As seen in Madison, WI

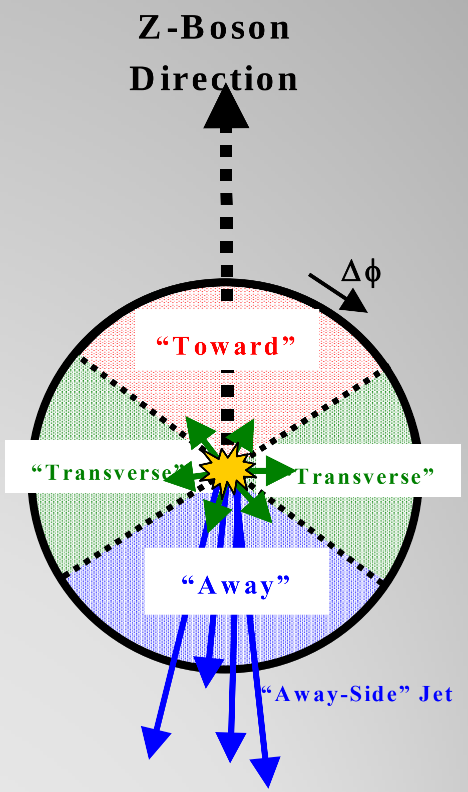
Additional Material

Z-Boson Production at Tevatron

Single Z Bosons are produced with large p_T via the ordinary QCD sub processes:

$$qg \to Zq,\ q\bar{q} \to Zg,\ \bar{q}g \to Z\bar{q}$$

They generate additional gluons via bremsstrahlung – resulting in multi-parton final states **fragmenting into hadrons** and forming **away-side jets**.



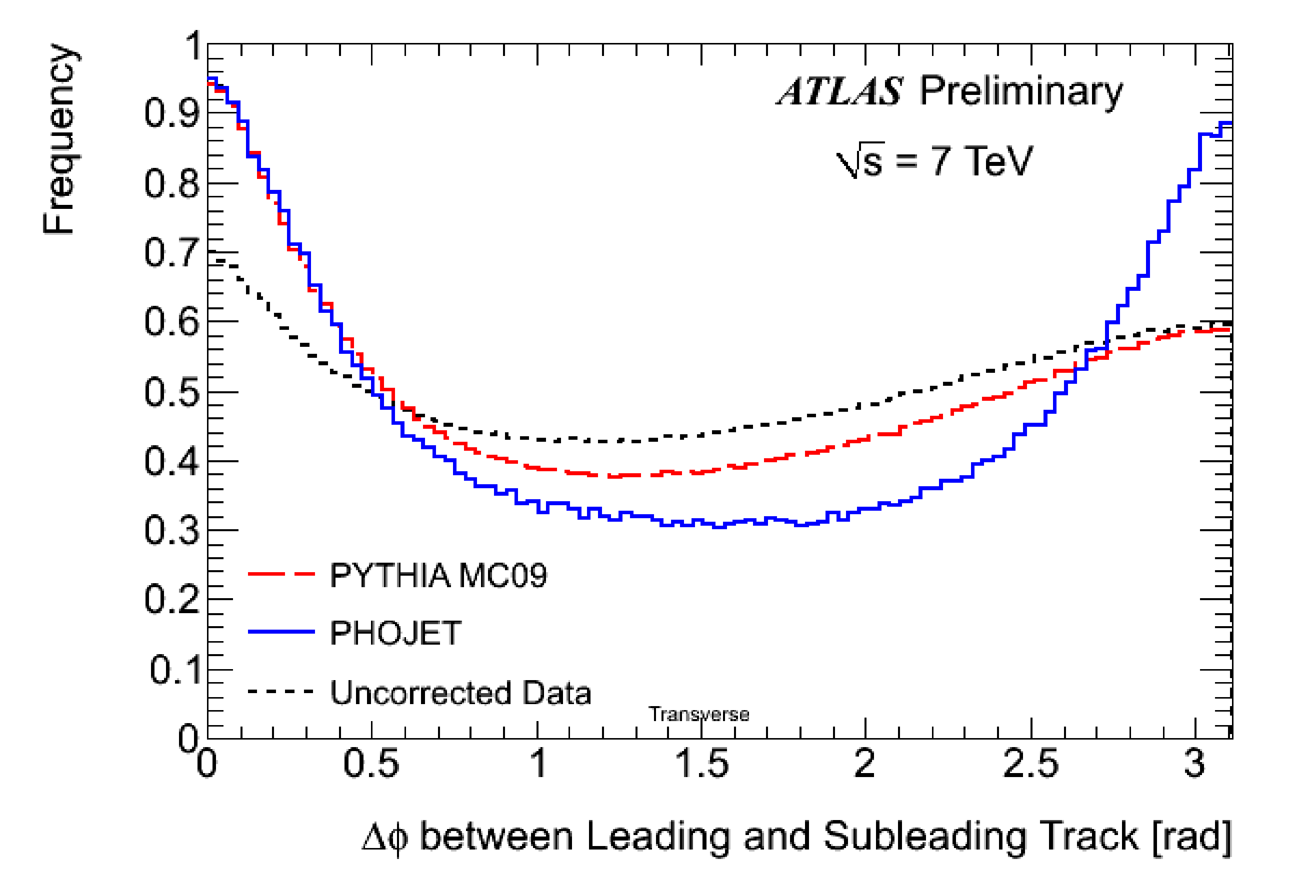
	CDF (pb)	NNLO (pb)
$\sigma(Z \to l^+l^-)$	254.9±3.3(stat)±4.6(sys)±15.2(lum)	252.3±5.0

CDF: Phys. Rev. Lett. 94, 091803 (2005)
NNLO Theory: Stirling, Van Neerven

Monte-Carlo Models

- **MC09:** Uses pT -ordered shower, color reconnection which minimizes the total string length, the ISR and MPI cutoff scales are separated. Uses the MRST LO* pdf.
- **DW:** Maximal ISR, virtuality-ordered shower. To fit D0 dijet $\Delta\Phi$ distribution.
- **Perugia0:** By Peter Skands, mostly using Tevatron and SppS min-bias data. Uses pT -ordered shower and CTEQ5L pdf.
- **PHOJET:** Dual Parton Model based, using pomeron exchange for soft and leading order perturbative QCD for hard interactions. Incorporates a model for high-mass diffraction dissociation including multiple jet production and recursive insertions of enhanced pomeron graphs.
- **HERWIG+JIMMY:** These have similar leading order matrix elements as PYTHIA, but use an angle-ordered parton shower, and a cluster hadronisation model. For the underlying event, HERWIG 6 is linked to JIMMY to provide multiplepartonic interactions

Effect of Reorientation



Estimates the relative frequency with which an event is reoriented. If the reconstructed leading track were missed, but the second higher pT was not, these profiles show the probability density for the event re-orientation.

Validates the final PYTHIA unfolding.

Event and Track Selection

Dataset	Taken in	Luminosity	Events
900 GeV	December, 09	7 μb^{-1}	189164
7 TeV	March-April 10	168 μb^{-1}	6927129

- Single-arm MBTS trigger, and no model dependent corrections or extrapolations.
- Leading track with with p_T > 1 GeV, and $|\eta|$ < 2.5.
- All other tracks with p_T > 500 MeV

Efficiency Corrections

- Event Corrections: Events are weighted to compensate for possible ways in which the event could incorrectly fail the selection criteria. MBTS trigger efficiency and the primary vertex reconstruction efficiency are estimated as functions of the number of selected beam spot tracks in an event.
- The probability that due to the tracking inefficiency none of the candidate leading tracks are reconstructed in an event, resulting in that event not being considered is estimated from the track efficiencies.
- Track Corrections: Tracks are weighted to compensate for reconstruction inefficiencies.

ATLAS MC09 tune of PYTHIA was used as the MC model for these corrections.

Migration Correction

Bin-by-bin Unfolding to account for:

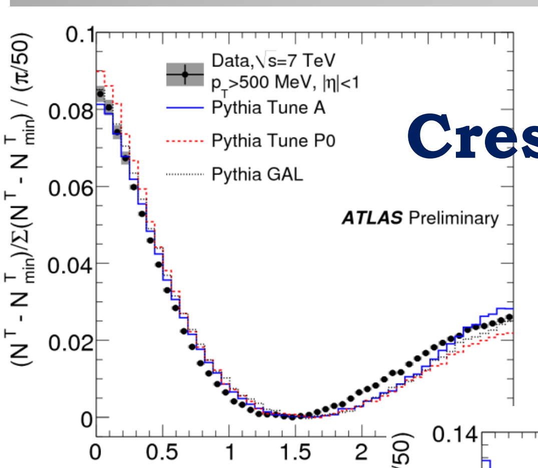
- Possible reorientation of the event.
- Bin-by-bin migration.
- Where there are sufficient statistics to make a comparison, the factors from PYTHIA & PHOJET agree within 2-4%.

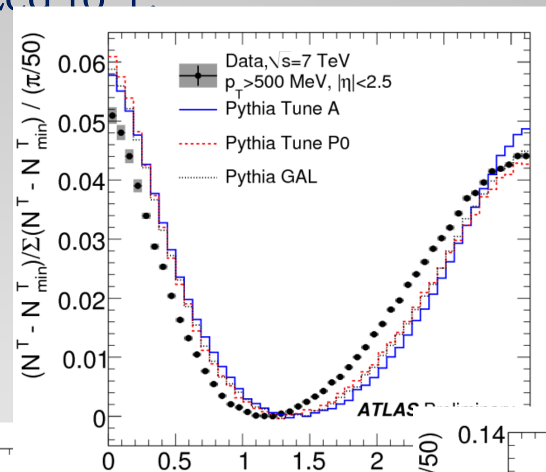
Generator level MC value of the observable divided by the reconstructed MC value after applying the event- and track-level efficiency corrections at each bin.

Complementary Way:

- Crest shape: Subtract the minimum of the distributions and normalized to 1.
- Same minus opposite: Subtracted the "opposite side" distribution from the "same side distribution" and normalized to 1.

Crest Shape



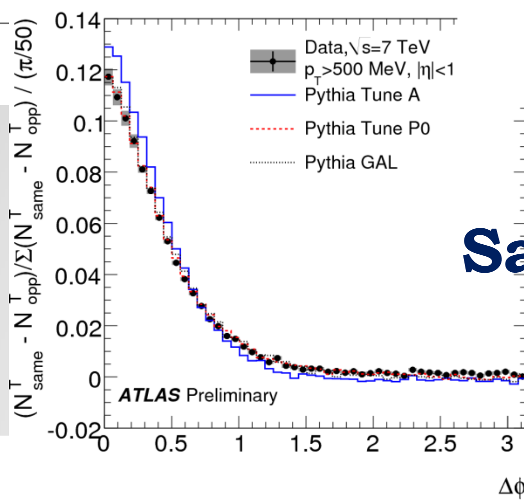


|η|< 2.5

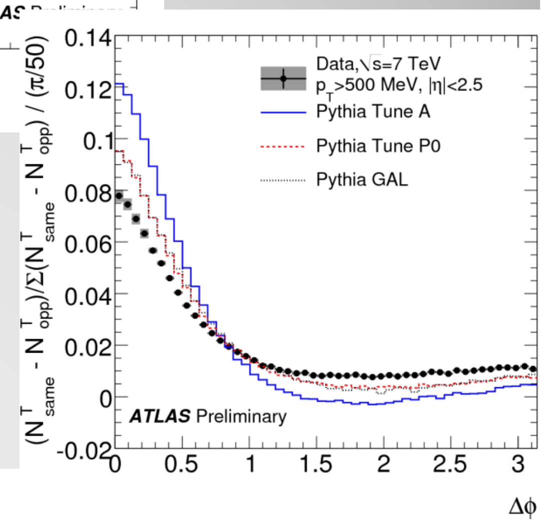
Data and MC not so good match

|η|< 1

Data and MC good match



Same - Opp



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